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TWO SIMPLE TOOLS FOR DESIGN OF FIXED SHADES

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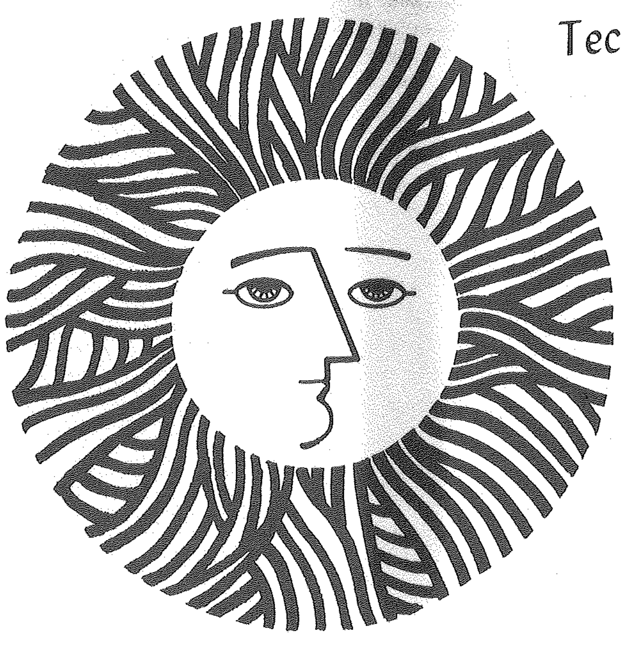

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TWO SIMPLE TOOLS FOR DESIGN OF FIXED SHADES*

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ABSTRACT

Two methods to assist designers in selecting and evaluating fixed, rectangular shading devices for rectangular wall and roof apertures early in the design process are presented. Both methods are based upon a simple mathematical technique called SHADE+. The first method is visual, using graphics prepared in advance by a computer program and the existing Libby-Owens-Ford Sun Angle Calculator to design appropriate shading during early stages of architectural design. The second method uses a Hewlett Packard 41C programmable calculator to refine the design by analysis of shading effects at specific hours, and to generate numerical data for use with detailed hand calculations of building loads. Each method is described, its advantages are noted, and an example of the use of each is given. Possible extensions and potential applications are discussed.

1. INTRODUCTION

The Passive Solar Group at Lawrence Berkeley Laboratory (LBL) is involved in the design and analysis of commercial buildings. Building design efforts demonstrated the need for a quick method to find appropriate shading devices for windows and other openings. The primary purpose of this paper is to describe the approaches developed in response to this need, demonstrate their effectiveness in providing accurate information early in the design process, and present them to architects, engineers, and solar designers who share our interest in developing solar design tools which are both affordable and appropriate to the task at hand.

The graphic method is described in Section 2, the calculator technique in Section 3, and possible extensions to both methods are discussed in Section 4.

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+Description of SHADE mathematical equations and logic is beyond the scope of this paper.

2. GRAPHIC OVERLAY METHOD OF SHADE DESIGN

Information from many sources must be integrated into the choice of a fixed shading device. The shade must be appropriate from the thermal, architectural, lighting, and economic viewpoints. The method presented here allows consideration of architectural and thermal qualities of a fixed shade. It can be extended to include consideration of lighting effects as well.

For this method, relevant information has been divided into two parts: that which describes the environment into which the shade is to be placed (inside and outside temperatures, building loads, and thermostat settings), and that which describes the shade and window geometries. Each type of information is used to construct a chart. When the two charts are overlaid, they describe the shading provided by a particular combination of shade, window, building, and climate throughout the year.

2.1 Sun Chart: Climate and Building Data

The position of the sun through the course of the year and during each day must be known. The mechanism used for this is the standard Libbey-Owens-Ford Sun Angle Calculator shown in Fig. 1. It shows a projection of the sky dome, with the position of the sun located for any day and hour that it would be shining. The distance from the center of the chart indicates sun altitude, where the center of the chart represents an overhead position and the circumference represents the horizon. Angular direction about the center indicates sun azimuths, with north at the top. Each chart gives the sun locations at a single latitude, 40°N in this case, using solar time.

The designer divides the chart into three zones: times at which cooling is required and solar gain should be discouraged, times at which heating is required and solar gain should be encouraged, and times at which no load is generated or conflicting requirements occur. These three zones will identify the need for sun or shade for each sun position.

A method of identifying the zones is described by Olgyay and Olgyay [1]. They recommend use of a 70°F outside temperature as the dividing line between overheated and underheated periods. The method described here uses a more detailed approach which can nevertheless be applied easily. The edges of the zones represent "balance points" - outside temperatures at which a building's heat losses and internal loads can maintain desired inside temperatures without auxiliary heating or cooling. Estimates of the balance points can be made from experience. Alternatively, simple hand calculations can identify balance points with reasonable accuracy; the Bin Method [2] is particularly effective. Balance points can be found with greater accuracy by reviewing the results of energy analysis computer programs.

Outside temperature data for representative climates should be provided in any publication of shade charts resulting from this project. Adjustments can be made for local variations. By comparing the balance points for heating and cooling with the outside temperatures at different times, the zones can be plotted easily. An example of a completed sun chart with the three zones is shown in Fig. 1.

2.2 Shade Chart: Shade/Window Geometry

Further information required to make an evaluation of any shading configuration are the geometric data of the shade relative to the window. A simple case consists of a vertical, rectangular window with a horizontal, rectangular shade centered over the window. The configuration is defined by five parameters: window width, window height, shade length, shade width, and distance from top of window to the shade. No window orientation need be specified here as the calculations are made for a range of hypothetical sun positions relative to the window.

For a particular configuration and a specific sun position relative to the window, SHADE calculates the percentage of the total window area which is shaded and the solar intensity reduction due to the incident sun angle variations. The end effects of the overhang and its shadow are accounted for in the calculations. These calculations are made for a matrix of relative sun positions, every 15^{o} of azimuth, and every 10^{o} of altitude. The results are plotted on a chart as illustrated in Fig. 2.

The shade chart is based on the same altitude/azimuth geometry as the sun chart described above. The major difference is the orientation: the sun chart is oriented to the compass directions, whereas the shade chart is oriented normal to the window. The effects of various window orientations can be seen by rotating the two charts relative to each other, as shown in Fig. 3.

Each shade chart represents the window/shade configuration drawn in the upper left corner. The size of each plotted box indicates the relative solar intensity on the window at that angle assuming the direct normal intensity is constant (solar intensity is actually much lower when the sun is very near the horizon). The blackened area represents the percentage of the window shaded from direct radiation. The open area of each box therefore represents the percentage of available beam sunlight which reaches the glass. The properties of the glass are not taken into account in this method, as it has no direct bearing on the periods of solar desirability, only on the magnitude of its effect once it is accepted.

It is not anticipated that the designer will have to generate shade charts for the configurations he wishes to check. There is a large but finite number of representative window/shade configurations. With the computer program, large numbers of shade charts can be generated very quickly and inexpensively making it possible to produce a large library of shade charts.

2.3 Example of Graphic Technique

Passive solar and conservation retrofits are planned for a light industrial building in Philadelphia. The building has moderate internal loads during the day and evening. It has a large expanse of windows on the southeast facade. One row is a series of regularly spaced 9' by 15' windows. It will be well insulated, but the planned retrofit will still permit substantial infiltration. In the course of planning the retrofit, computer simulations on the building with no shading specified resulted in loads diagrammed on the sun chart in Fig. 1.

Twenty-four shade charts for windows with a height:width ratio 1.0:0.6 (= 5:3) were compared with the sun chart to find the best shade. (The relationship between the window and shade is independent of scale, so each parameter is expressed by its ratio with the window height.) The actual comparison provides a quick visual analysis of the agreement between the shading needed (shown on the sun chart) and the shading provided (shown on the shade chart.) The orientation of the windows on the sunchart ("SOUTHEAST" in Fig. 3) is placed over the "NORMAL TO APERTURE" axis on the shade chart. The areas of interest are those in which the heating and cooling load zones overlap with the boxes. Where no boxes occur, no beam radiation will reach the window. Boxes outside the sun paths represent sun positions which cannot occur relative to a window in the given orientation.

Interpretation of the charts is simple. The ideal shade will show black boxes inside the overheated area, and open boxes inside the underheated area. The closer to this ideal, the better the thermal performance of the shade. This must be subjectively weighed by the designer against the architectural qualities of the resulting facade. The shade chosen may not provide optimal thermal benefits, but retain a balance of shading, architectural, and economic advantages.

In this example, a very good solution to the building's thermal needs is the 15' long, 6' wide shade 3' above the window, shown in Fig. 3. However, architecturally and economically, the designer might prefer the 9' by 6' shade right at the top of the window shown in Fig. 2. These factors might outweigh the fact that the windows will be partially shaded during the winter. If this second choice were made, the designer has identified a winter shading problem, and could take action to seasonally remove or adjust the shades to allow more winter sun into the building. Alternatively, more detailed design of the shade might lead to a solution with reduced winter shading. This can be done early in the design, when a full range of options is still available.

3. CALCULATOR METHOD OF SHADE EVALUATION

To obtain more precise estimates of shade/aperture design trade-offs, a programmable calculator can be used effectively as a design tool, since alphanumerical strings can be programmed to act as prompts for input, output, and decision branch points. Hence it is easy for the designer to become familiar with and to use the calculator software, since there is little risk of entering raw data incorrectly or of misinterpreting output.

3.1 Description of Calculator Method

In its present form, the program begins with a series of prompts for input, including the type of opening (window or door) and the type of shading device (overhang or side fin). The surface containing the opening is assumed to be vertical, with the overhang or fin lying perpendicular to this surface. Additional prompts for input include the width, length, and location of the overhang or fin with respect to this opening; the solar altitude angle; and the building solar azimuth angle with respect to the building normal.

Output, returned within 2-3 seconds, consists of the percentage of the total area of the opening which is shaded; the shaded area itself; the cosine of the angle of incidence between the sun and the surface; the direct normal solar intensity; and the total amount of direct solar power incident upon the opening. These outputs are followed by two additional prompts for input, the first for changing the solar altitude and building azimuth, the second for changing elements of the shade/opening geometry.

However, since the software does not calculate solar transmission and absorption of glazings, the program does not determine the direct solar gain to glazed enclosures. In addition, the software does not calculate indirect solar contributions from the sky and ground, so that the program is only indirectly useful in determining building heating and cooling loads. On the other hand, because the direct beam component of sunlight is of primary concern in sun control design, the program is useful in preliminary design to achieve acceptable levels of solar penetration during the heating and cooling seasons. Little time is required to proceed from input to output and design parameters are easy to change; hence this approach can be used to estimate various preliminary design trade-offs between economic costs, energy savings, and aesthetic appearances.

3.2 Example of Calculator Method

In the case of the Philadelphia study discussed in Section 2, two possible choices were discussed. For comparison, Table 1 below shows the HP 41C output for both cases, namely the percentage of shading, total sunlit area, and total incident direct solar power (the three righthand columns), such that the better thermal solution (Fig. 3) appears without parenthesis, and the alternate (Fig. 2) appears with them. This data is listed for various solar hours, insolation, building azimuth and solar altitude angles, for a surface facing the southeast at 40^{o} latitude, on the 21st day of January and July (in the left hand columns). These two months were chosen, on the assumption that they provide a reasonably correct estimate of worst case heating and cooling demands, at least as far as the direct solar heat gain is concerned.

Inspection of the results shows that by reducing the length of the 15' overhang to 9' and by placing it immediately above the window, roughly comparable results are obtained. Whereas the better thermal design provides 156.2 MBtu/day and 70.6 MBtu/day of incident solar power during 21 January and July, the alternate case provides 135.4 MBtu/day and 60.9 MBtu/day under the same conditions. Hence, due to a slight "over-design" in the overhang width for the alternate case, both January and July shading reduces the daily incident solar power by 86-87% of that available in the best case. This analysis suggests that raising the alternate overhang slightly and/or reducing its width slightly would provide approximately the same results as the original case. Such changes could be investigated using the same technique.

4. EXTENSIONS OF SHADING DESIGN METHODS

The graphic overlay and calculator methods described above are only the first step in the development of more general design tools. The computer program could be improved to include the capability of producing shade charts for fins and a variety of louvered shading devices, either as shades above a window or as screens in front of one. Awnings and shades for horizontal and tilted skylights could also be added. In addition, the calculator method could be extended so that solar hour angles at particular latitudes and months of the year can be determined without referring to external tabulations. In this way, the incident solar radiation calculations can be summed automatically, including effects of diffuse sunlight. In principle, solar gains, with shading, could be calculated for use in early heating and cooling load calculations, such as the ASHRAE Solar Heat Gain Factor approach [3].

The daylighting effect of shades is very difficult to determine. The usefulness of daylight is a function of so many variables--size and proportions of the room, reflectivity of surfaces, control of beam sunlight, location of windows--that the same window/shade configuration may have entirely different effects on daylighting in different situations. However, by making a consistent set of assumptions about daylighting, the relative daylighting potential resulting from given window/shade configurations could be demonstrated. Techniques to identify and communicate the daylighting effects of shading are extremely important to future development of these methods.

5. SUMMARY

There is a need for simple, quick tools to provide direction to the building designer, especially at early stages of the design process. This paper presents methods for initial choice of fixed shades based on thermal and architectural performance, and later refinement and analysis of the shades. Although the techniques as currently developed have limited scope, they can form the basis for extensions to deal with more complex shading geometries and related issues such as daylighting. It is expected that practicing building designers as well as researchers will be involved in the development of these tools.

6. REFERENCES

(1) Olgyay, Aladar and Victor Olgyay, Solar Control and Shading Devices, Princeton University Press, pp. 78-81, 86-87 (1959)

(2) ASHRAE Systems Handbook, American Society of Heating, Refrigerating, and Air Conditioning Engineers, pp. 43.11-43.17 (1980).

(3) Cooling and Heating Load Calculation Manual, American Society of Heating, Refrigerating, and Air Conditioning Engineers, pp. 3.25-3.39 (1979).

FIGURE 1. Sun Chart: Philadelphia Light Industrial Building

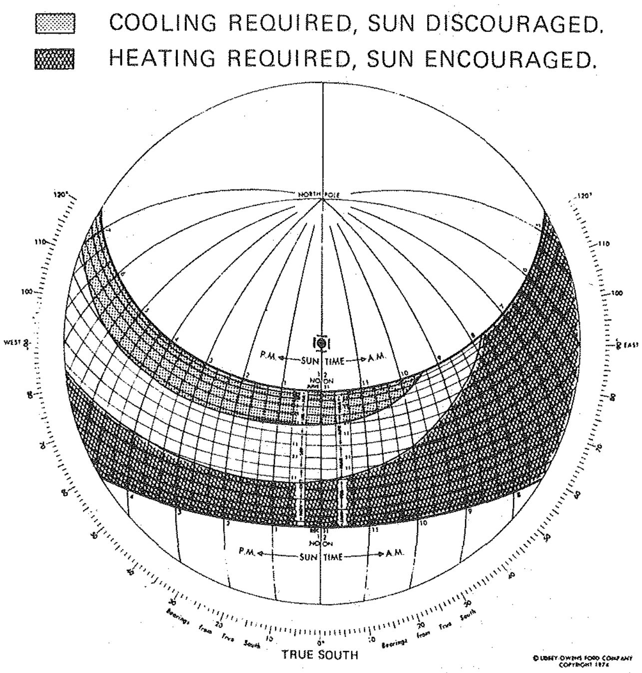


FIGURE 2. Shade Chart: Geometry as Shown in Key Drawing

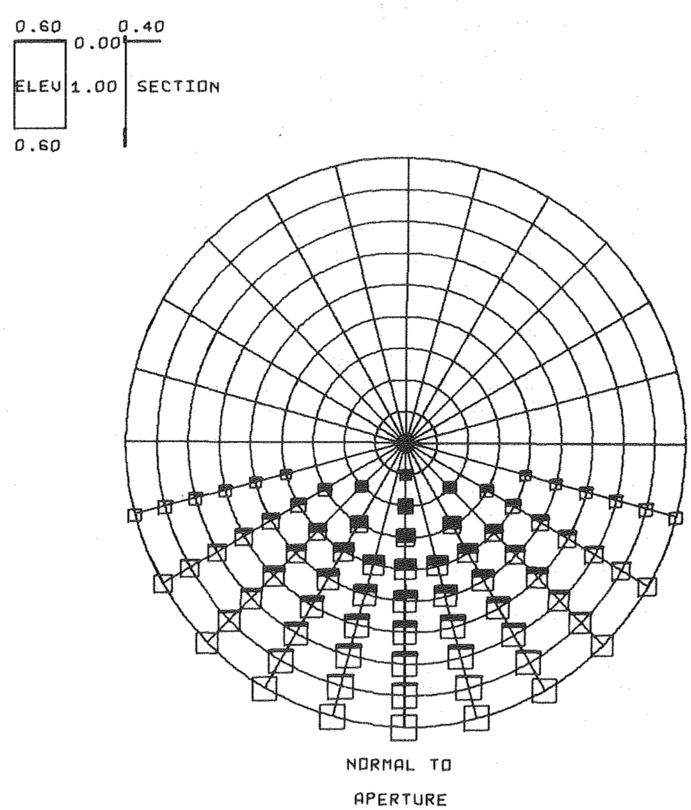
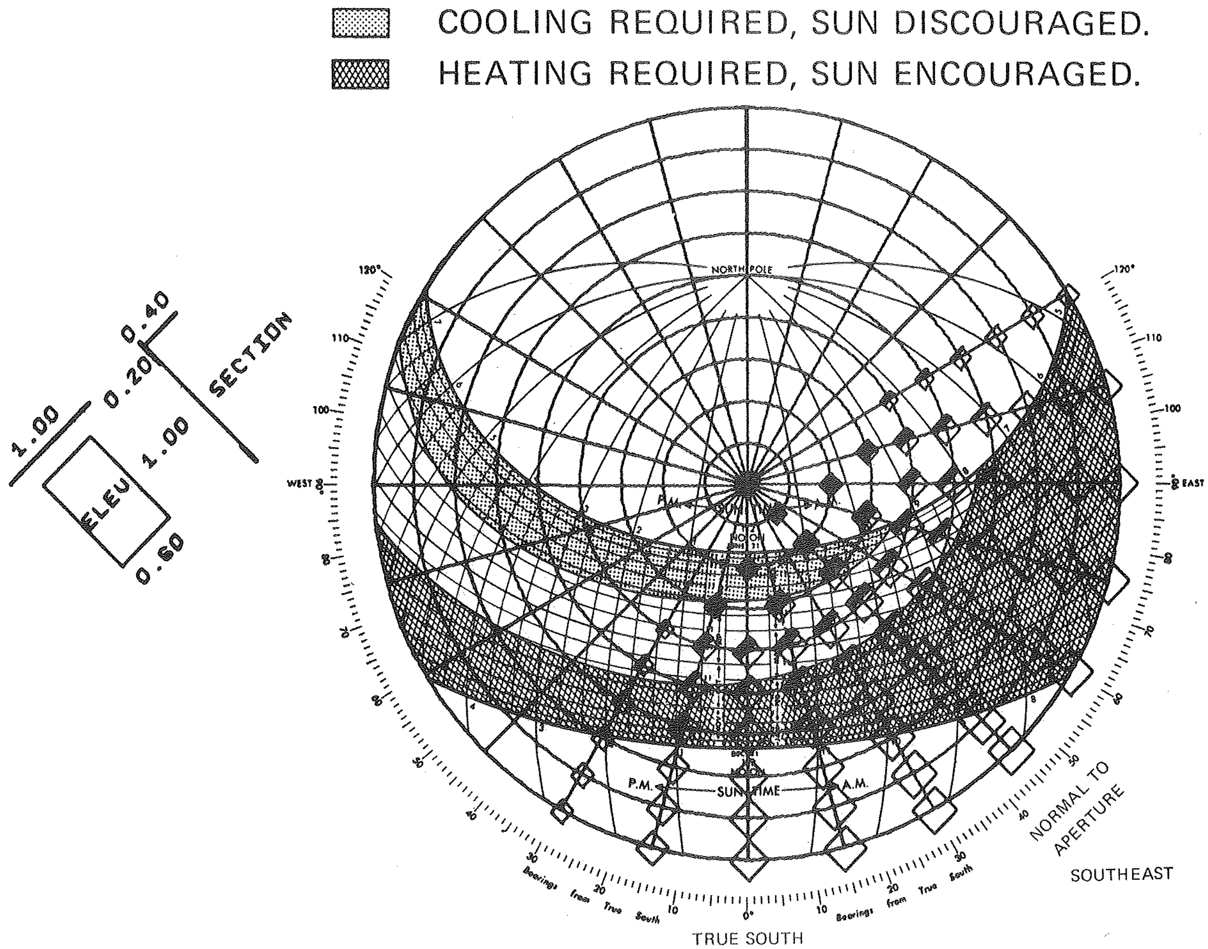


FIGURE 3. Overlay of Sun and Shade Charts



Date	Solar Time	Direct Normal Insolation (Btu/ft^{2}hr)	Solar Altitude (Deg.)	Solar Azimuth (Deg.)	% Shade		Sunlit Area (ft^2)		Incident Solar (MBtu/hr)	
Jan. 21	8 am	142	8	10	0.0	(5.4)	135.0	(127.8)	18.7	(17.7)
	9	239	17	1	0.0	(12.2)	135.0	(118.6)	30.9	(27.1)
	10	274	24	14	0.0	(16.8)	135.0	(112.3)	32.8	(27.3)
	11	289	28	29	4.3	(19.8)	129.2	(108.2)	28.8	(24.2)
	12 pm	294	30	45	10.1	(21.8)	121.4	(105.6)	21.9	(19.0)
	1	289	28	61	10.9	(18.2)	120.3	(110.4)	14.9	(13.7)
	2	274	24	76	5.1	(13.8)	128.2	(116.4)	7.8	(7.0)
	3	239	17	89	0.5	(9.2)	134.3	(122.6)	0.5	(0.5)
							Incident Total (MBtu/day)	=	156.2	(135.4)
July 21	6 am	138	13	61	0.0	(7.9)	135.0	(124.3)	8.8	(8.1)
	7	208	24	52	5.5	(16.6)	127.6	(112.6)	14.9	(13.2)
	8	241	35	42	15.5	(26.4)	114.1	(99.4)	16.7	(14.6)
	9	259	47	31	29.8	(40.0)	94.8	(81.0)	14.4	(12.3)
	10	269	57	16	44.1	(58.0)	75.5	(56.8)	10.6	(8.0)
	11	275	66	8	70.7	(86.5)	39.5	(18.3)	4.4	(2.0)
	12 pm	276	70	45	96.2	(78.6)	5.2	(29.0)	0.3	(1.9)
	1	275	66	82	79.5	(63.3)	27.6	(50.6)	0.4	(0.8)
							Incident Total (MBtu/day)	=	70.6	(60.9)

Table 1. Summary of HP41C Output for Case Study (Section 3.2)